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Be Shell Wall Thickness By SEM Analysis

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From: Bob Cook

Subject: Be shell wall thickness by SEM analysis.

I was worried a bit about the SEM wall thickness measurement. The fracture may not be normal to the surface so what Ed tries to do is capture a picture where the edge of the shell surface is tangent to the line of sight, so that even if the fracture is not normal to the surface the SEM photo would be "normal" to the surface, and thus the wall thickness measurement would be accurate. However to the extent that the capsule surface is not tangent to the line of sight, the wall will appear thicker than it is, and the resulting density will be low.

The calculation below attempts to quantify this. Consider Figure 1. In the best case the SEM would catch the vertical line as the wall thickness. But if the image is tilted by some angle θ , then the apparent wall will be measured as w . How much bigger is w as a function of θ than the actual wall thickness, which is $Ro - Ri$?

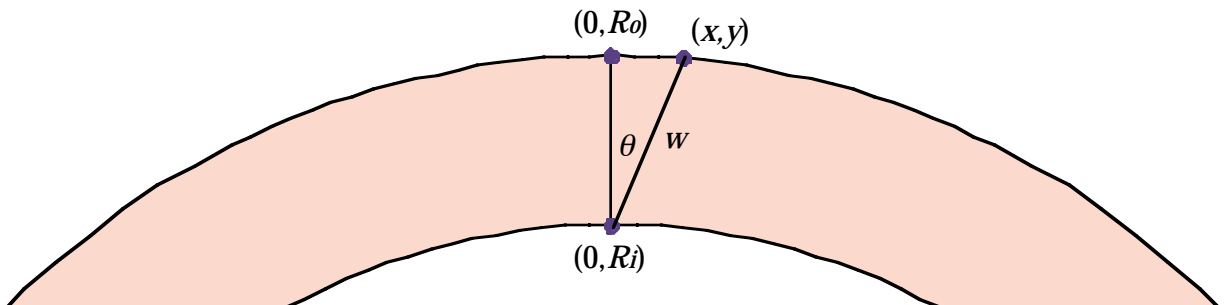


Figure 1. Identification of terms.

The equation of the line between $(0, Ri)$ and (x, y) is

$$y = \cot(\theta) \cdot x + Ri \quad (1)$$

and that of the outer wall is

$$x^2 + y^2 = Ro^2 \quad \text{or} \quad y = \sqrt{Ro^2 - x^2} \quad (2)$$

Thus to determine the coordinates of their intersection, (x, y) , we simply need to equate the two expressions:

$$\cot(\theta) \cdot x + Ri = \sqrt{Ro^2 - x^2} \quad (3)$$

and solve for x giving

$$x = \frac{-Ri \cdot \cot(\theta) + \sqrt{Ro^2 - Ri^2 + Ro^2 \cot(\theta)^2}}{1 + \cot(\theta)^2} . \quad (4)$$

This result is then put back into eq 1 to give

$$y = Ri + \frac{\cot(\theta) \left(-Ri \cdot \cot(\theta) + \sqrt{Ro^2 - Ri^2 + Ro^2 \cot(\theta)^2} \right)}{1 + \cot(\theta)^2} . \quad (5)$$

The length w in Figure 1 is simply the length between $(0, Ri)$ and (x, y) or

$$w = \sqrt{x^2 - (y - Ri)^2} = \sin(\theta) \cdot \sqrt{Ro^2 \cdot \csc(\theta)^2 - Ri^2} - Ri \cdot \cos(\theta) . \quad (6)$$

Thank you *Mathematica*! In Figure 2 I plot $w - (Ro - Ri)$, the error in the wall thickness measurement as a function of the "tilt" angle θ for wall thicknesses of 30, 100, and 170 μm . It is actually the error relative to the wall thickness that we are concerned about, since this is directly proportional to the relative increase in the volume measurement and thus decrease in the computed density. Plots of this quantity are shown in Figure 3.

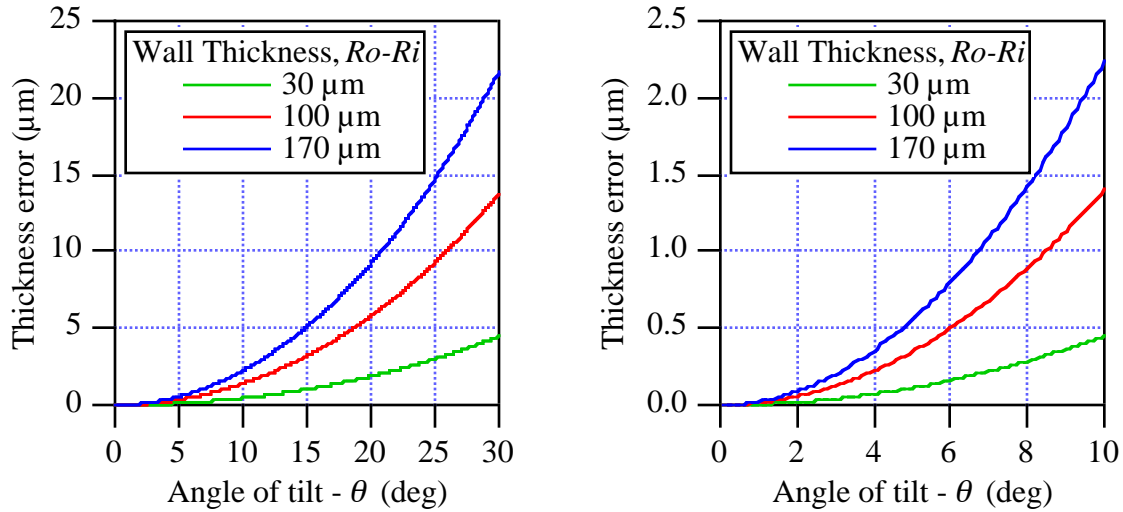


Figure 2. Plots of absolute error (excess wall thickness measured) as a function of the angle of "tilt" when taking the SEM image.

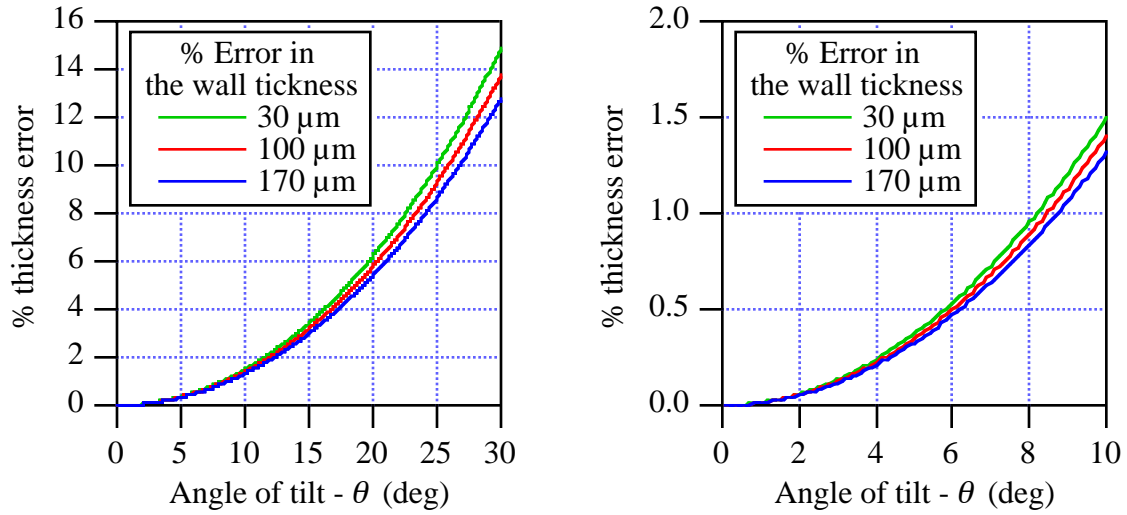


Figure 3. Plots of the error relative to the wall thickness.

What these plots show is that alignment so that the tilt angle is less than 6° results in less than a 0.5% error (lower) in the density, about 0.01 g/cm^3 for our Be shells. Not to be worried about. The error increases rapidly, however, a tilt angle error of 15° would result in a low density of about 0.06 g/cm^3 .

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